

# Analysis of Elevation Changes of Pine Island Glacier and Simulation of its Spatial Characteristics

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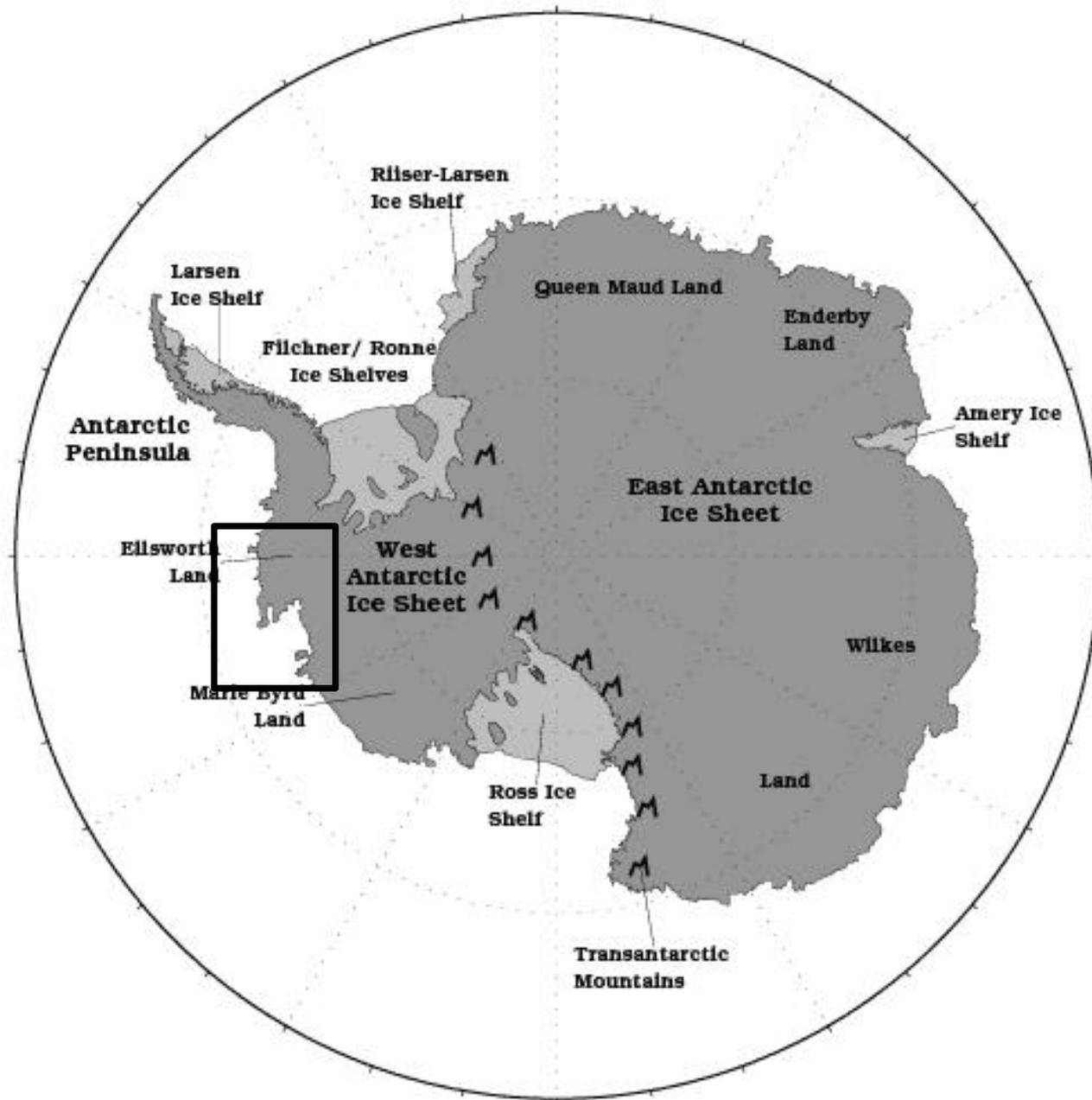
[herzfeld@tryfan.colorado.edu](mailto:herzfeld@tryfan.colorado.edu)



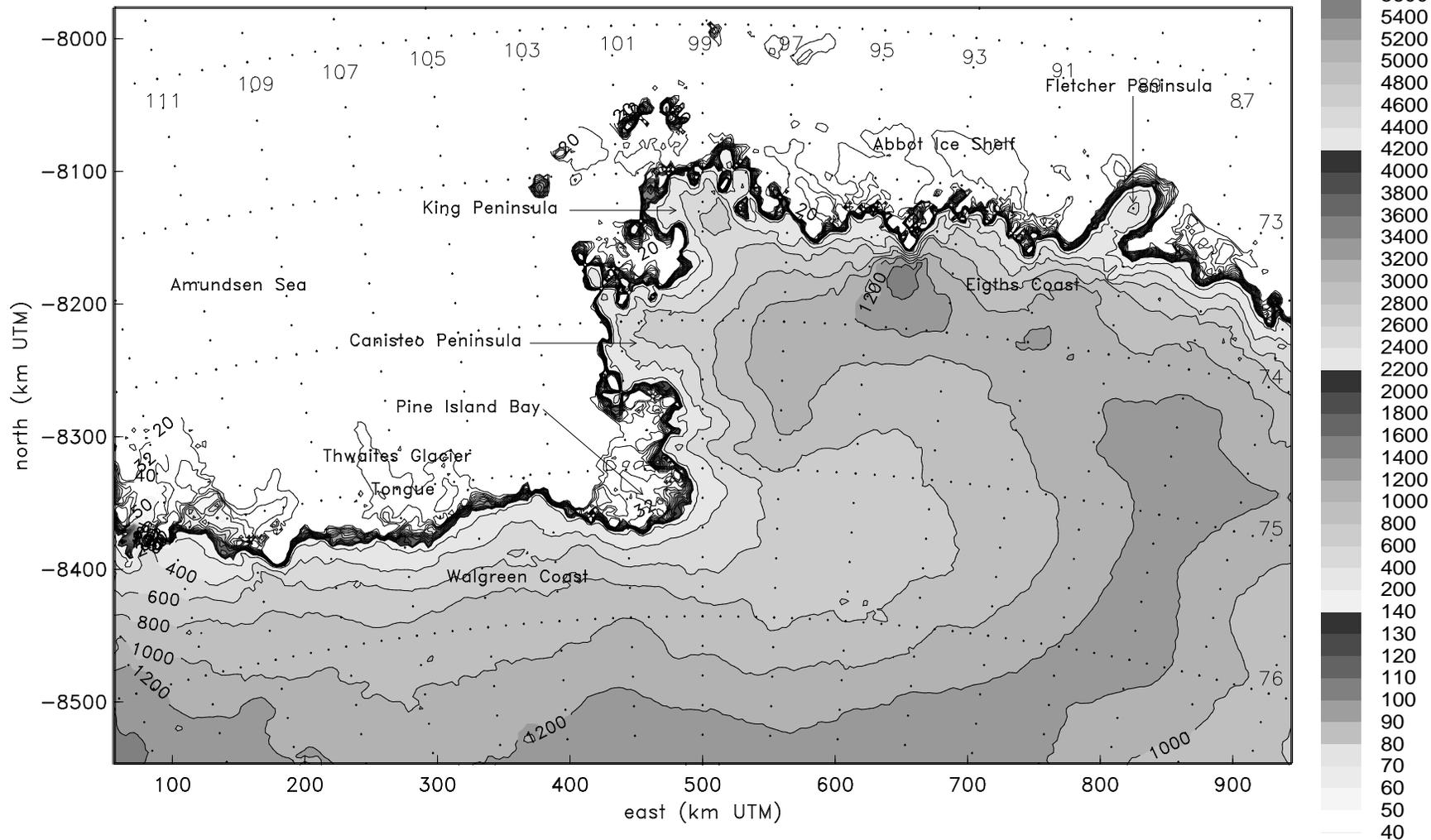
With input from

PatrickMcBricde, Bruce Wallin, Danielle Lirette, Steve Sucht,  
Jay Zwally, John DiMarzio

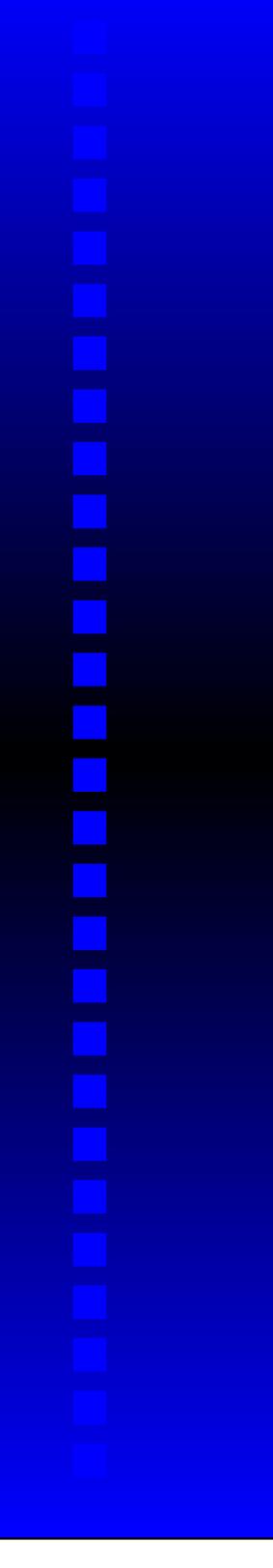
# Antarctica with Walgreen Coast (box)



# Walgreen Coast – ERS-1 DATA, 1995

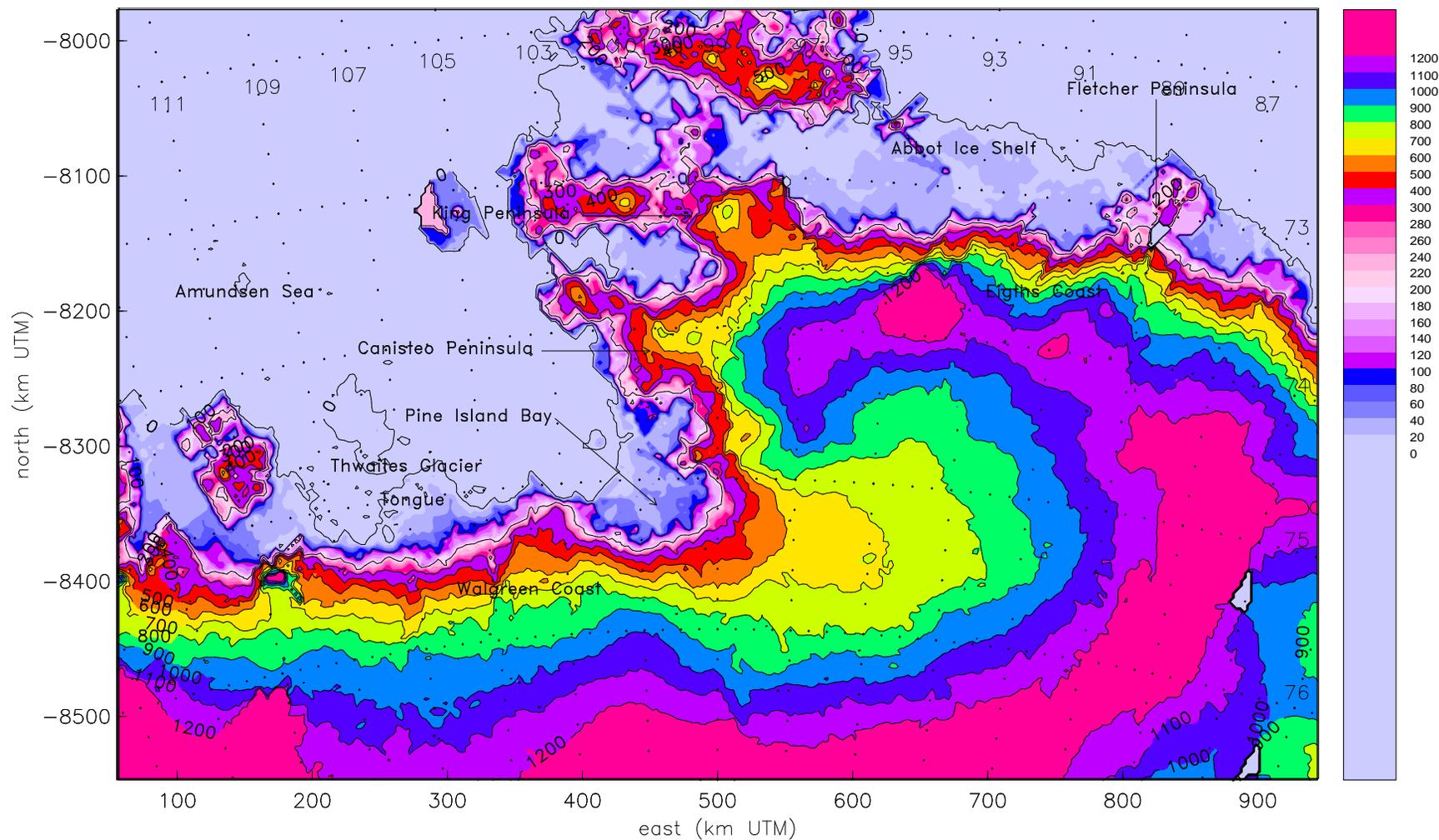


e243-279n71-77, WGS84, Gaussian variog., central mer. 261, slope corrected, scale 1:5000000, 980112



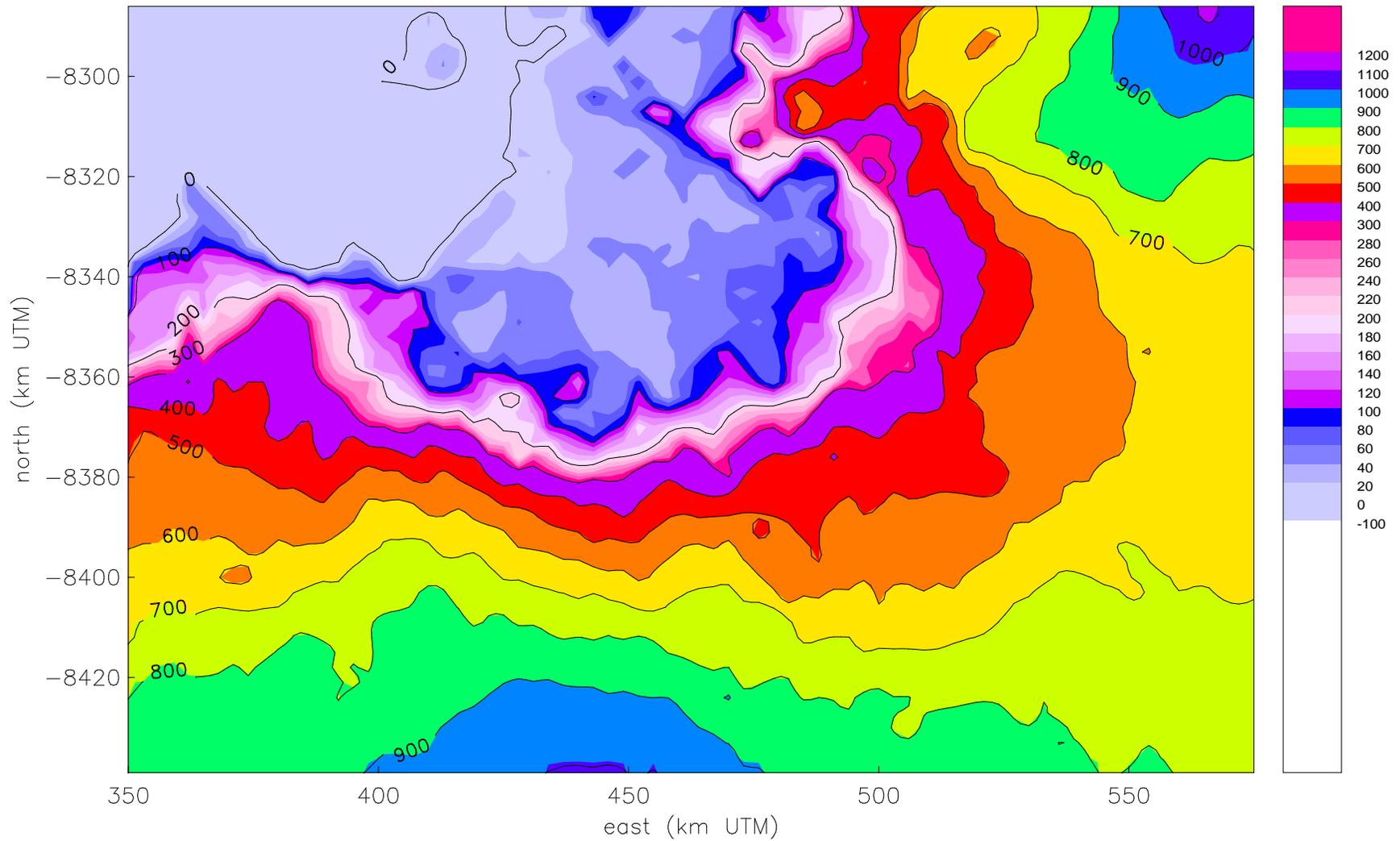
# The Role of Pine Island Glacier and Thwaites Glacier in Stability Scenarios for the West-Antarctic Ice Sheet

# Walgreen Coast – GLAS Data



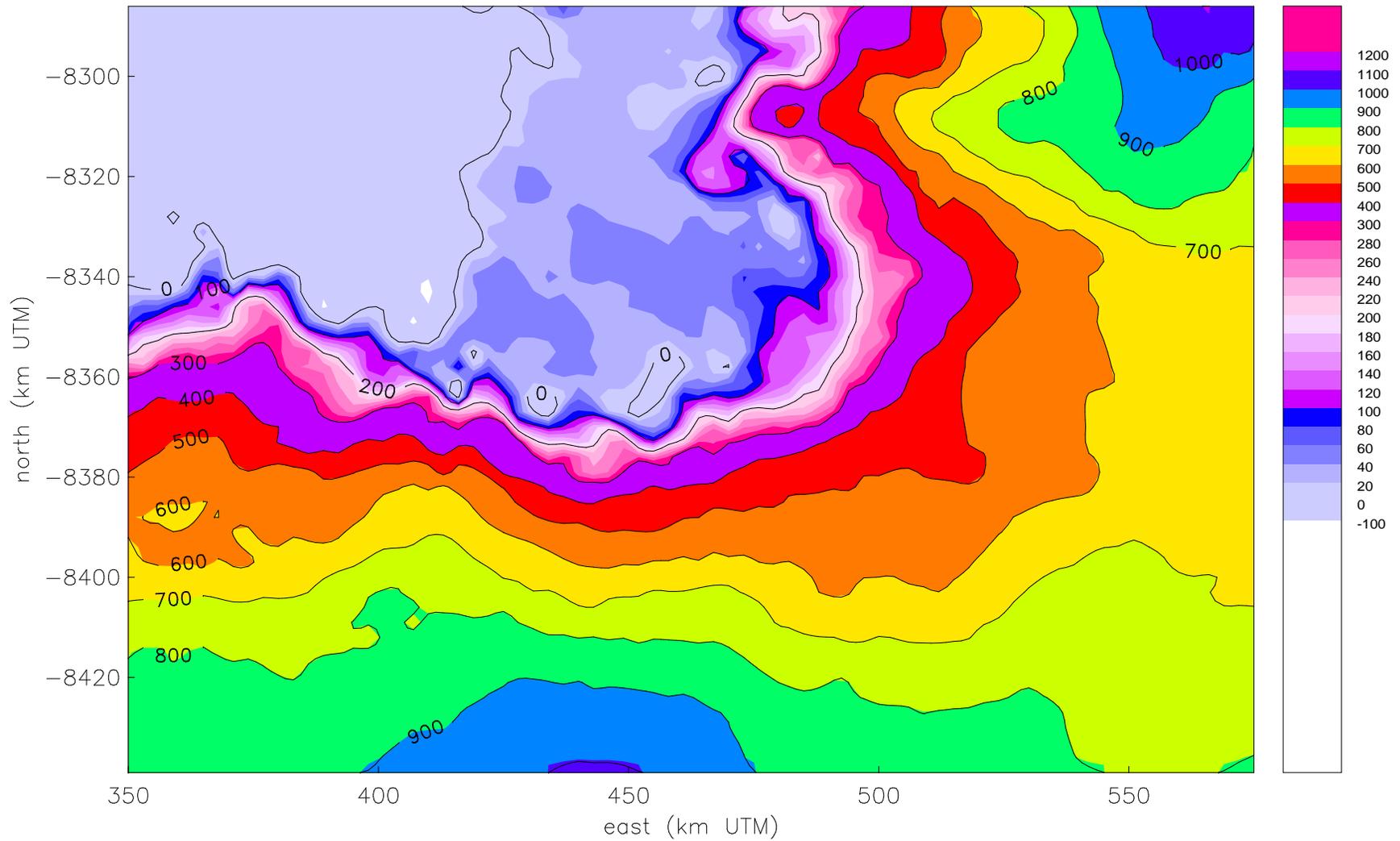
GLA06 Data, (Laser 2A, gain=crit, rel18), Oct/Nov 2003, vario(350,3450,6000m), search=rg 30km, 1:5000000, gla06.1.gain.0.col8

# Pine Island Glacier – GLAS Data



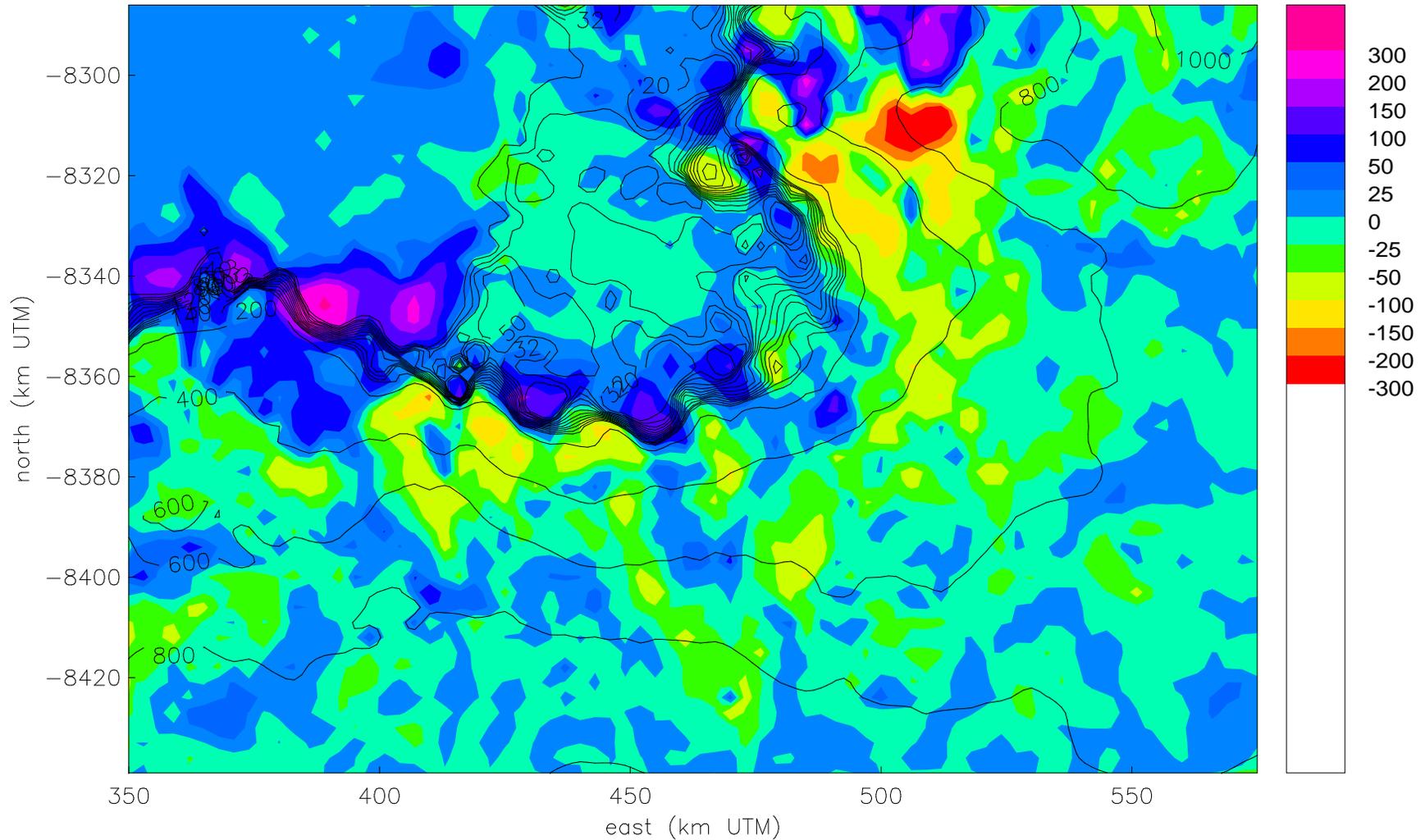
GLA06 Data, (Laser 2A, gain-crit, rel18), Oct/Nov 2003, vario(350,3450,6000m), search-rg 30km, 1:2000000, gla06.1.gain.smallpine2.v2.col8

# Pine Island Glacier – ERS-1 Data, 1995



1:2000000, m261e243-279n71-77.e.smallpine2.v2.col8

Pine Island Glacier – GLAS (2003) minus ERS-1 (1995) [with ERS-1 contours]



scale 1:2000000 diff glasgain-ers1.wers1cont.smallpine2.col10.v2.totps 20050404  
gla06.1.gain.smallpine2.0.dtm minus m261e243-279n71-77.e.smallpine2.0.dtm

# Results:

## ICESAt — Pine Island Glacier

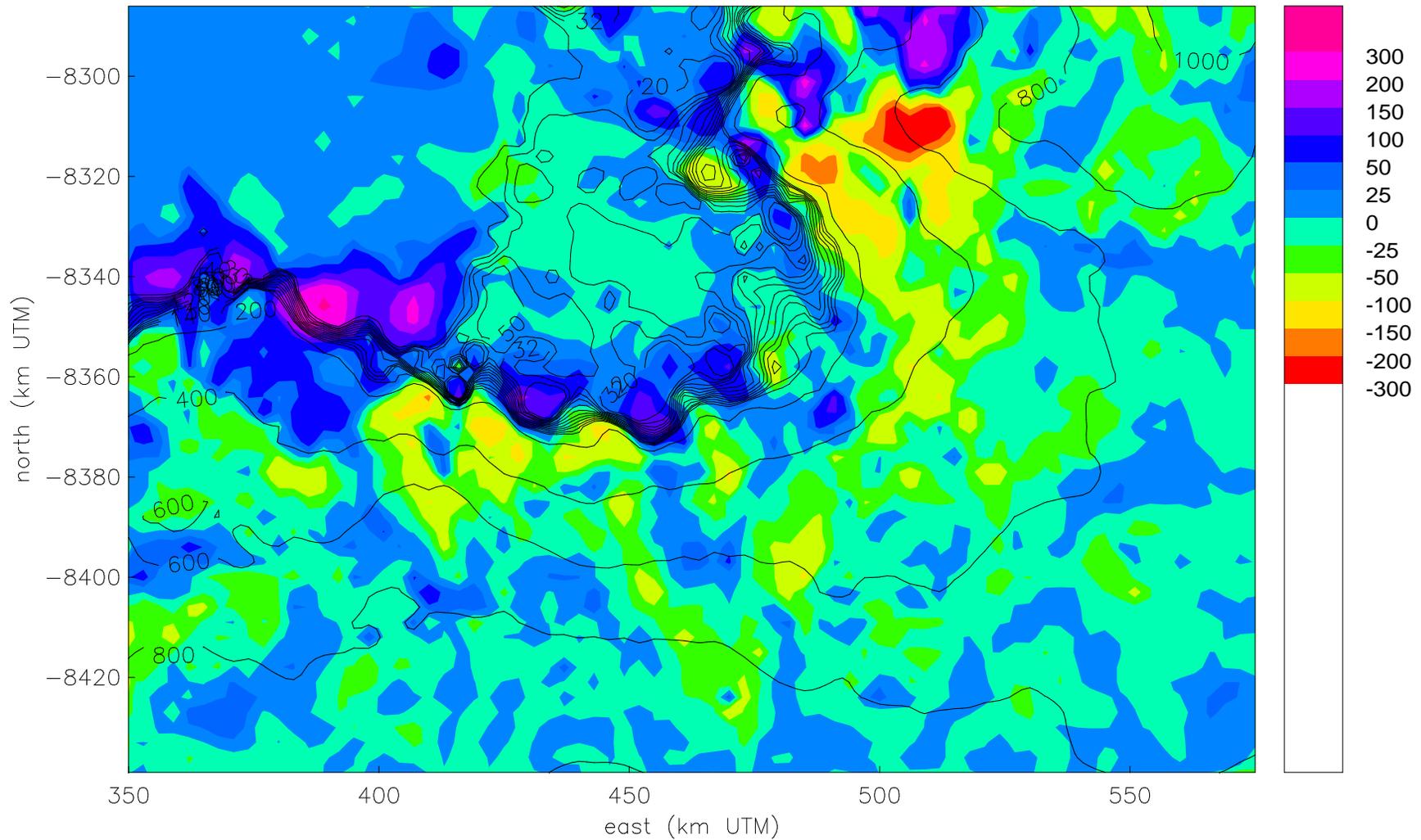
- GLAS measures ice surface altimetry with unprecedented accuracy and precision
- DEMs derived from GLAS data using geostatistical analysis can be utilized for elevation change detection, sufficient for geophysical analysis
- Thinning rates in Pine Island Glacier have been increasing
- The observed retreat of Pine Island Glacier is attributed to internal processes in the glacier, related to dynamic thinning

Herzfeld, McBride, Zwally, DiMarzio, 2008

Does this trend continue?

# Change over 8 years: 2005-1995

Pine Island Glacier – GLAS (2003) minus ERS-1 (1995) [with ERS-1 contours]

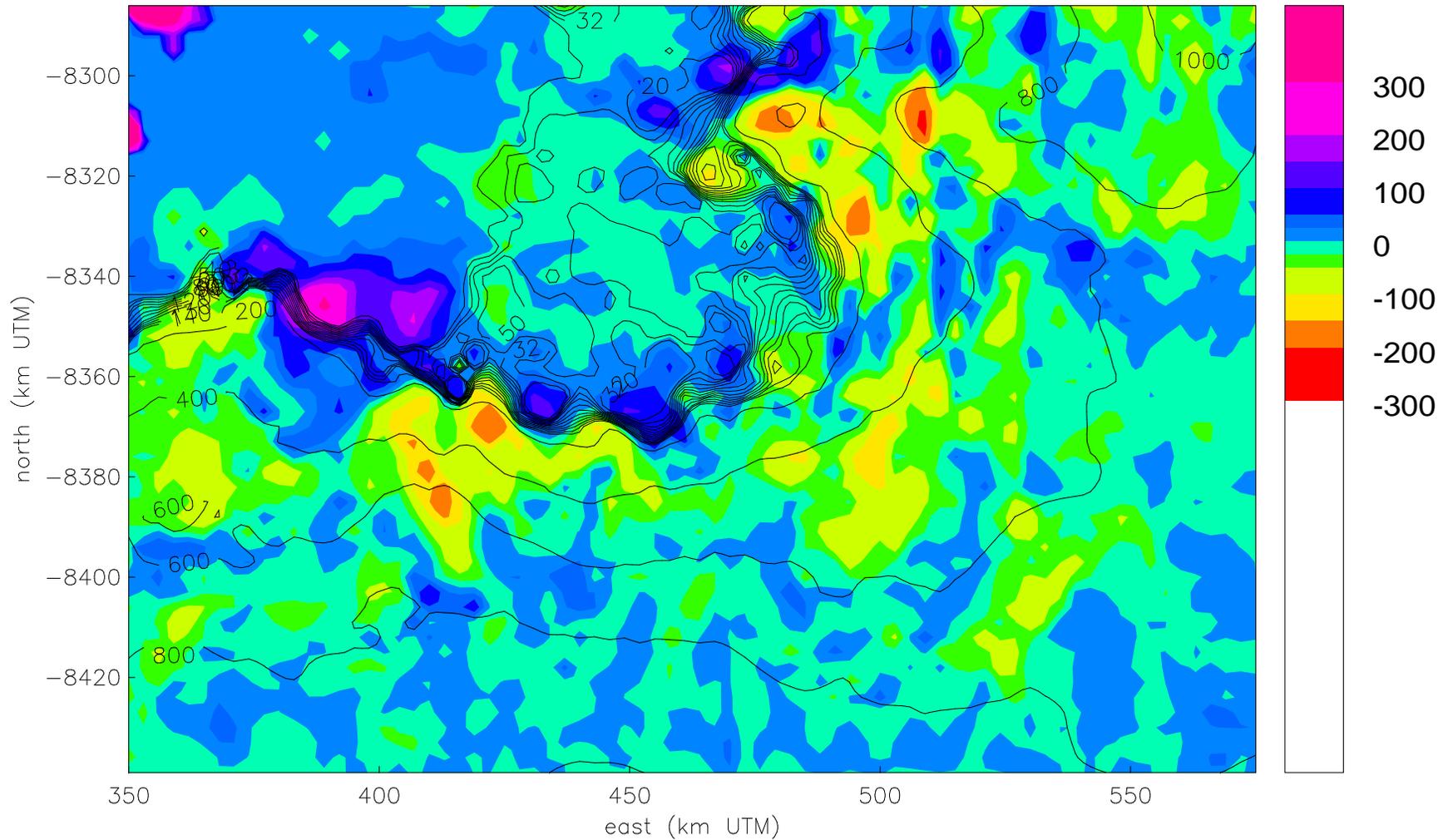


scale 1:2000000 diff glasgain-ers1.wers1cont.smallpine2.col10.v2.totps 20050404

gla06.1.gain.smallpine2.0.dtm minus m261e243-279n71-77.e.smallpine2.0.dtm

# Change over 10 years: 2005-1995

Pine Island Glacier – GLAS (2005-05, L3C) minus ERS-1 (1995) [ERS-1 cont]

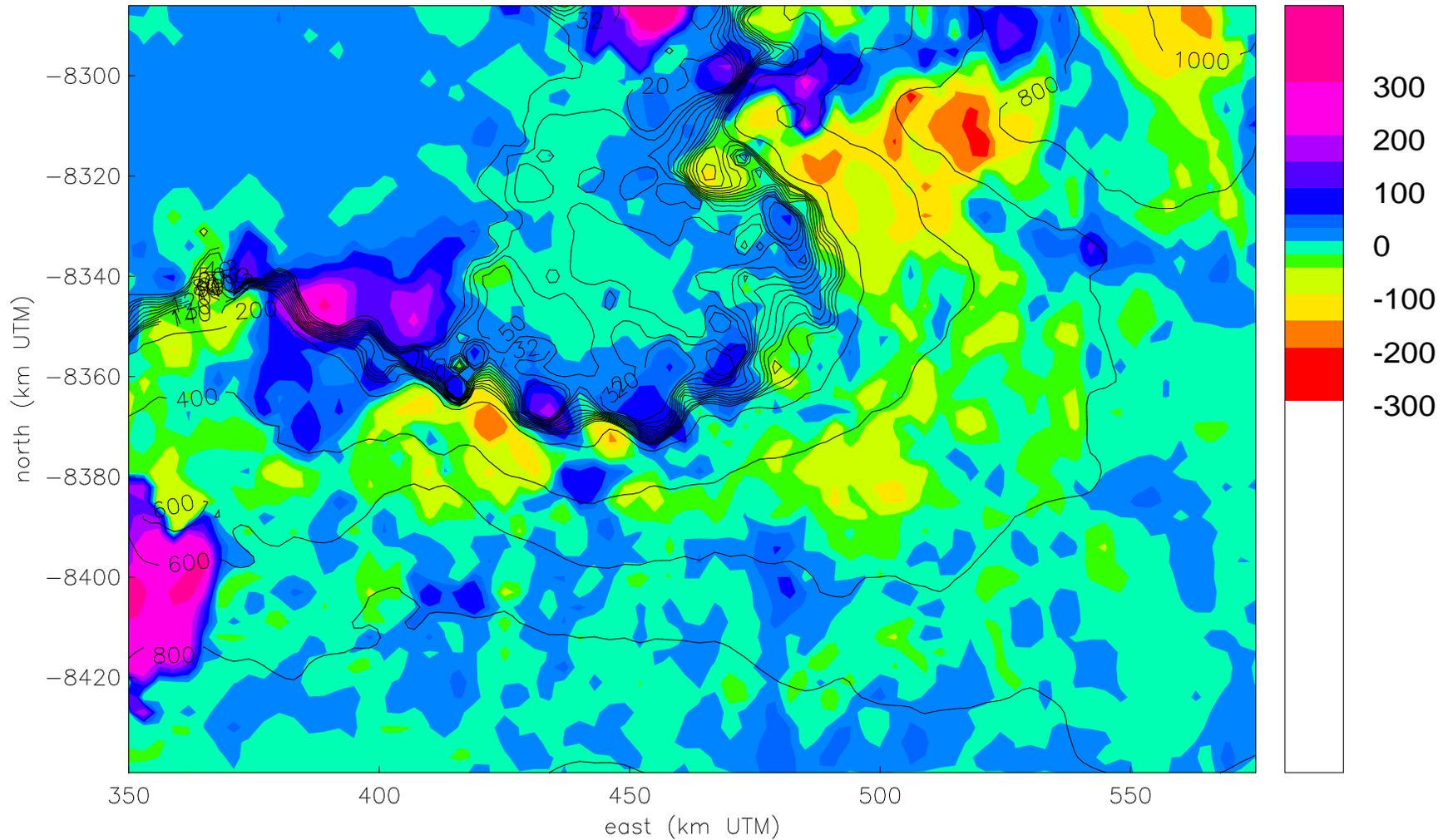


scale 1:2000000 diff.gla12 l3c-ers1.wers1cont.smallpine2.totps 20080927

gla12 rel28 l3c-ers1.dtm (diff.gla12 l3c-ers1.smallpine2.mx)

# Change over 11 years 2006 (L3E) -1995

Pine Island Glacier – GLAS (2006-02, L3E) minus ERS-1 (1995) [ERS-1 cont]

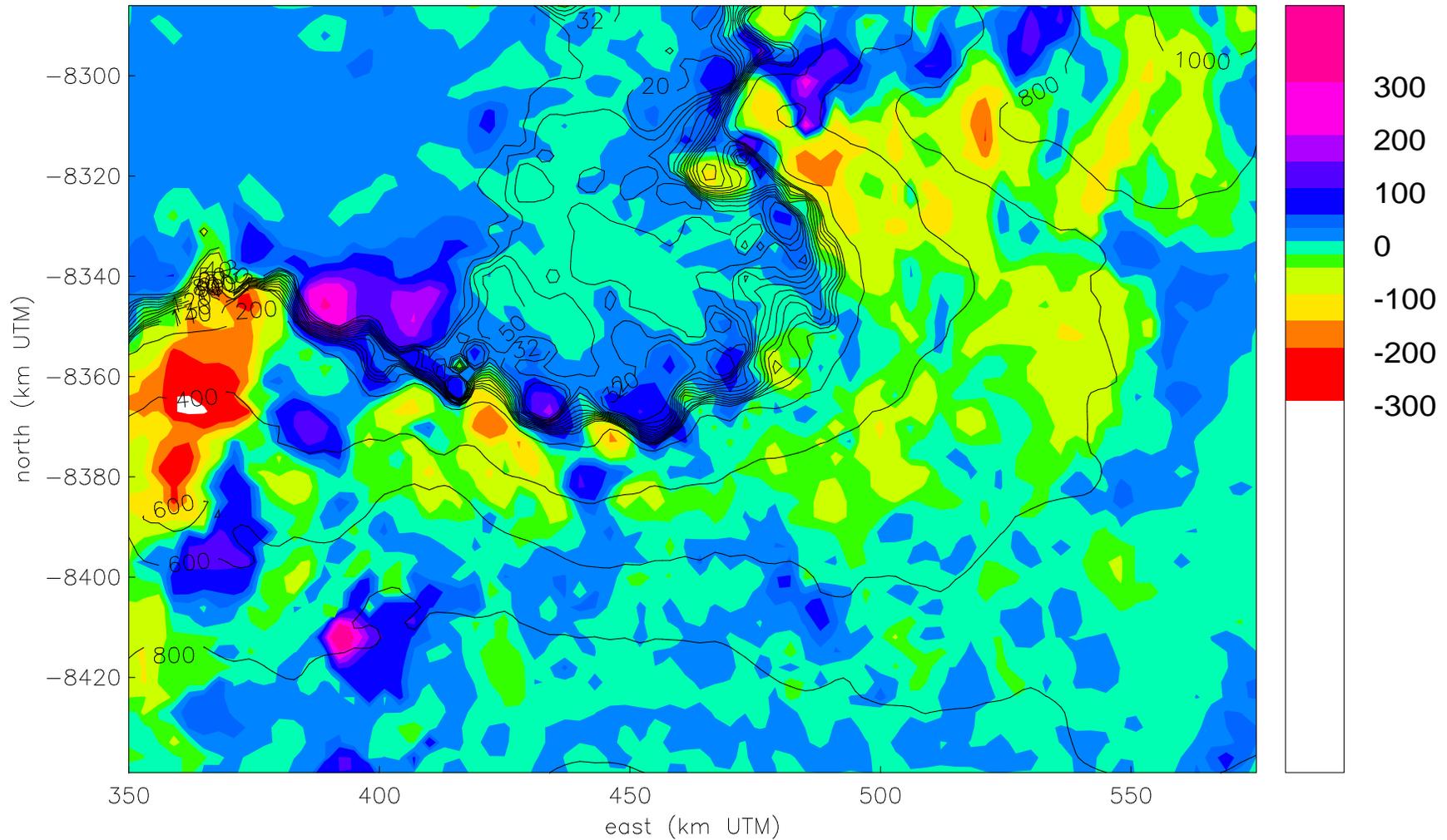


scale 1:2000000 diff.gla12 l3e-ers1.wers1cont.smallpine2.totps 200809027

gla12 rel28 l3e-ers1.dtm (diff.gla12 l3e-ers1.smallpine2.mx)

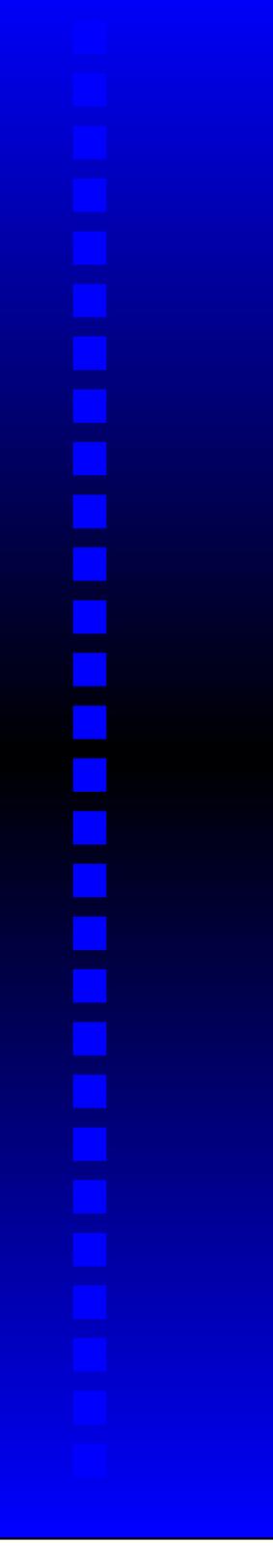
# Change over 11 years 2006 (L3F) -1995

Pine Island Glacier – GLAS (2006-05, L3F) minus ERS-1 (1995) [ERS-1 cont]



scale 1:2000000 diff.gla12 l3f-ers1.wers1cont.smallpine2.totps 200809027

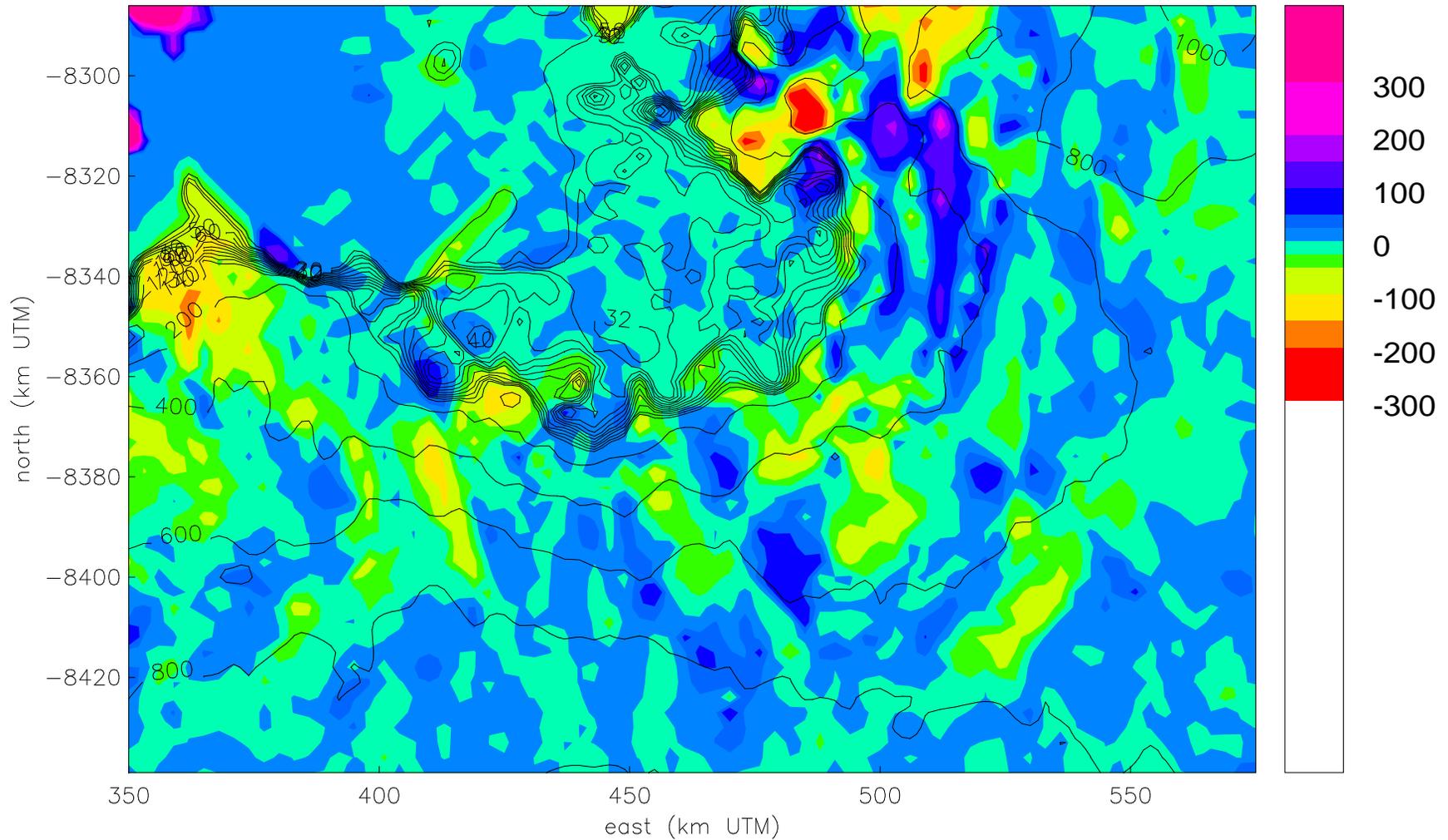
gla12 rel28 l3f-ers1.dtm (diff.gla12 l3f-ers1.smallpine2.mx)



Change in ICESat years —  
Analysis based on GLAS data only

# Change over 2 years 2005 (L3C) - 2003 (L2A)

Pine Island Glacier – GLAS (2005-05) minus GLAS (2003-10) [2003 cont]

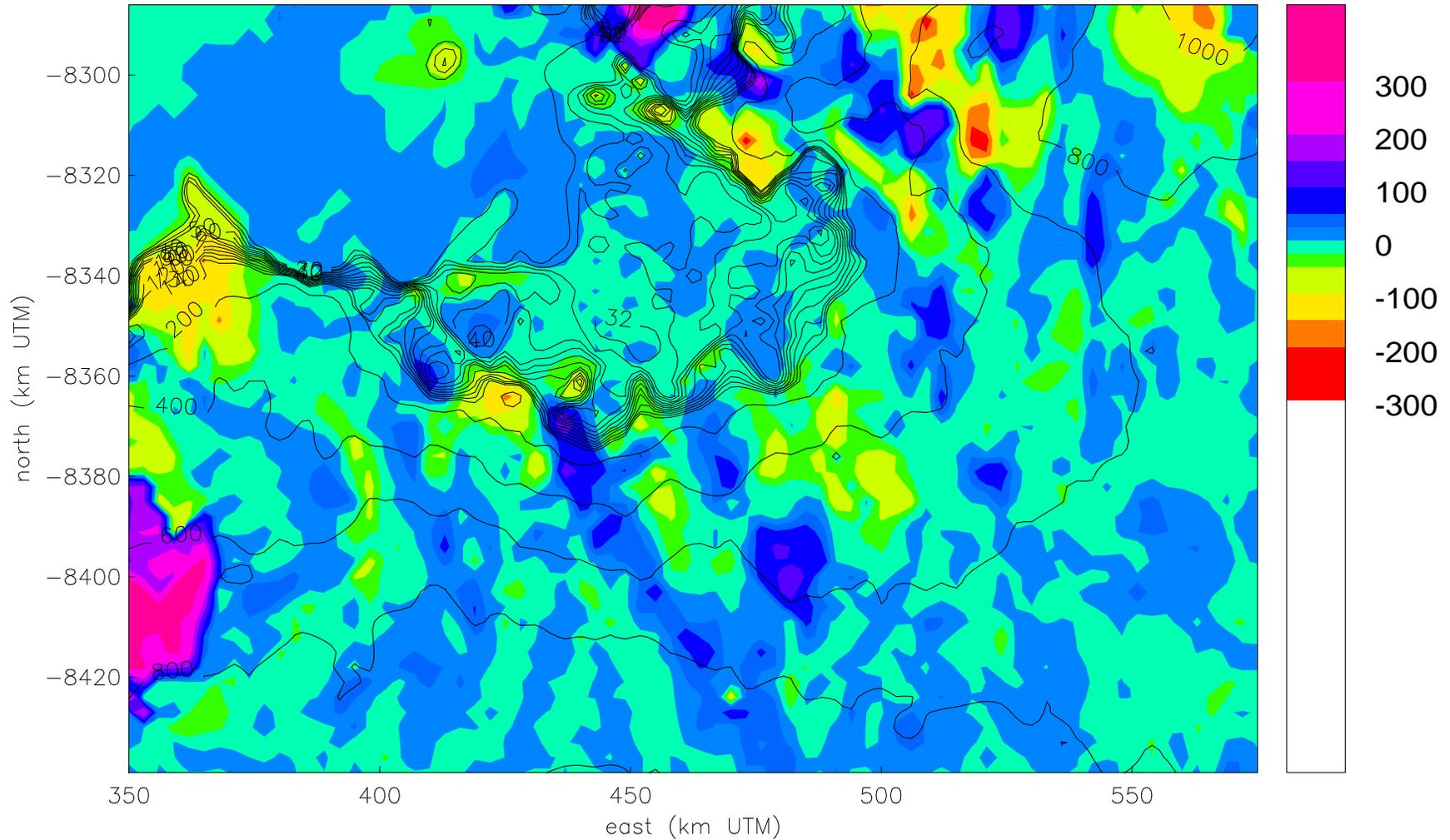


scale 1:2000000 diff.gla12 l3c-l2again.smallpine2.totps 20080927

diff.gla12 l3c-l2again.smallpine2.mx

# Change over 3 years 2006 (L3E) - 2003 (L2A)

Pine Island Glacier – GLAS (2006-02) minus GLAS (2003-10) [2003 cont]

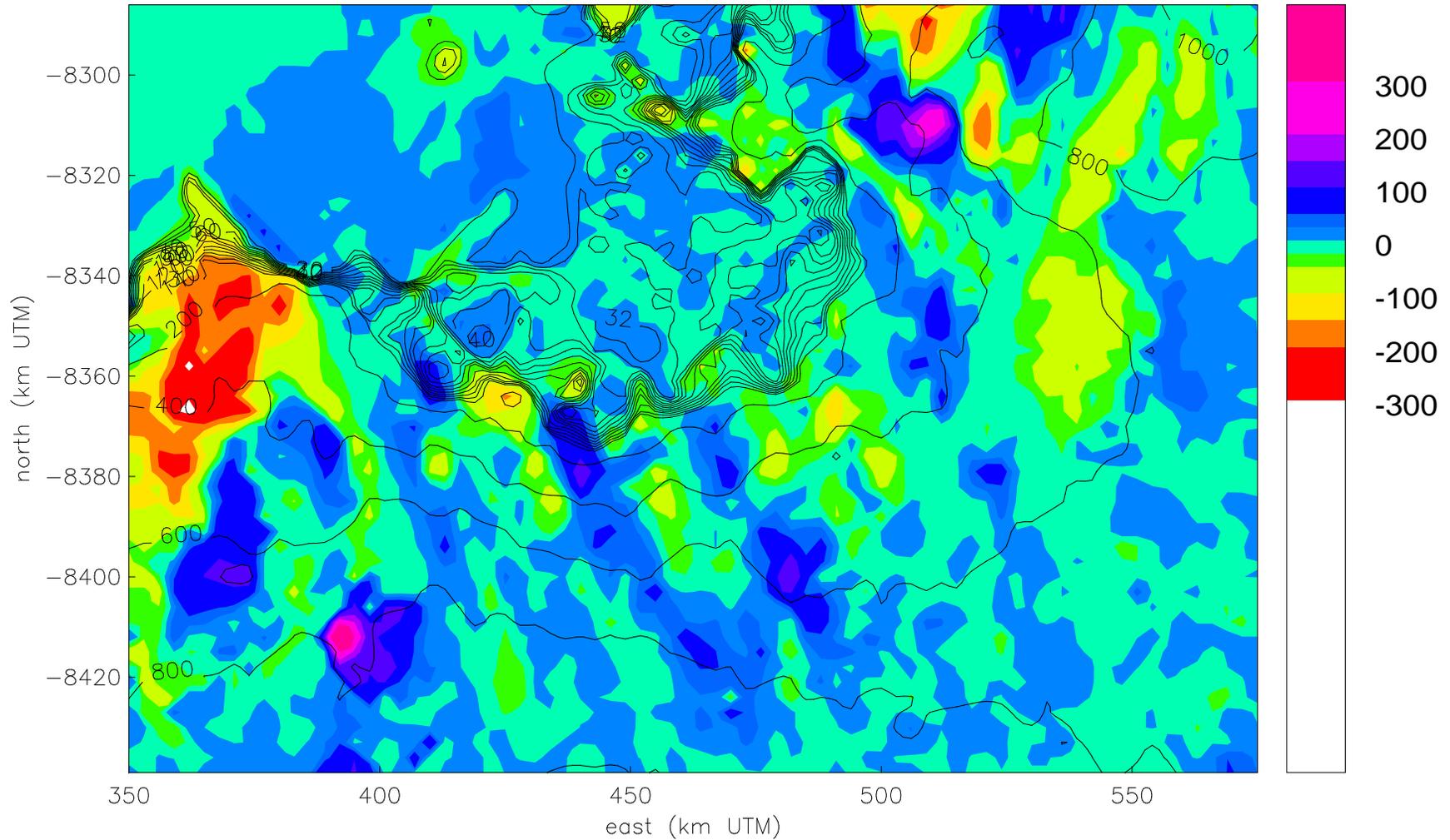


scale 1:2000000 diff.gla12 l3e-l2again.smallpine2.totps 20080927

diff.gla12 l3e-l2again.smallpine2.mx

# Change over 3 years 2006 (L3F) - 2003 (L2A)

Pine Island Glacier – GLAS (2006–05) minus GLAS (2003–10) [2003 cont]

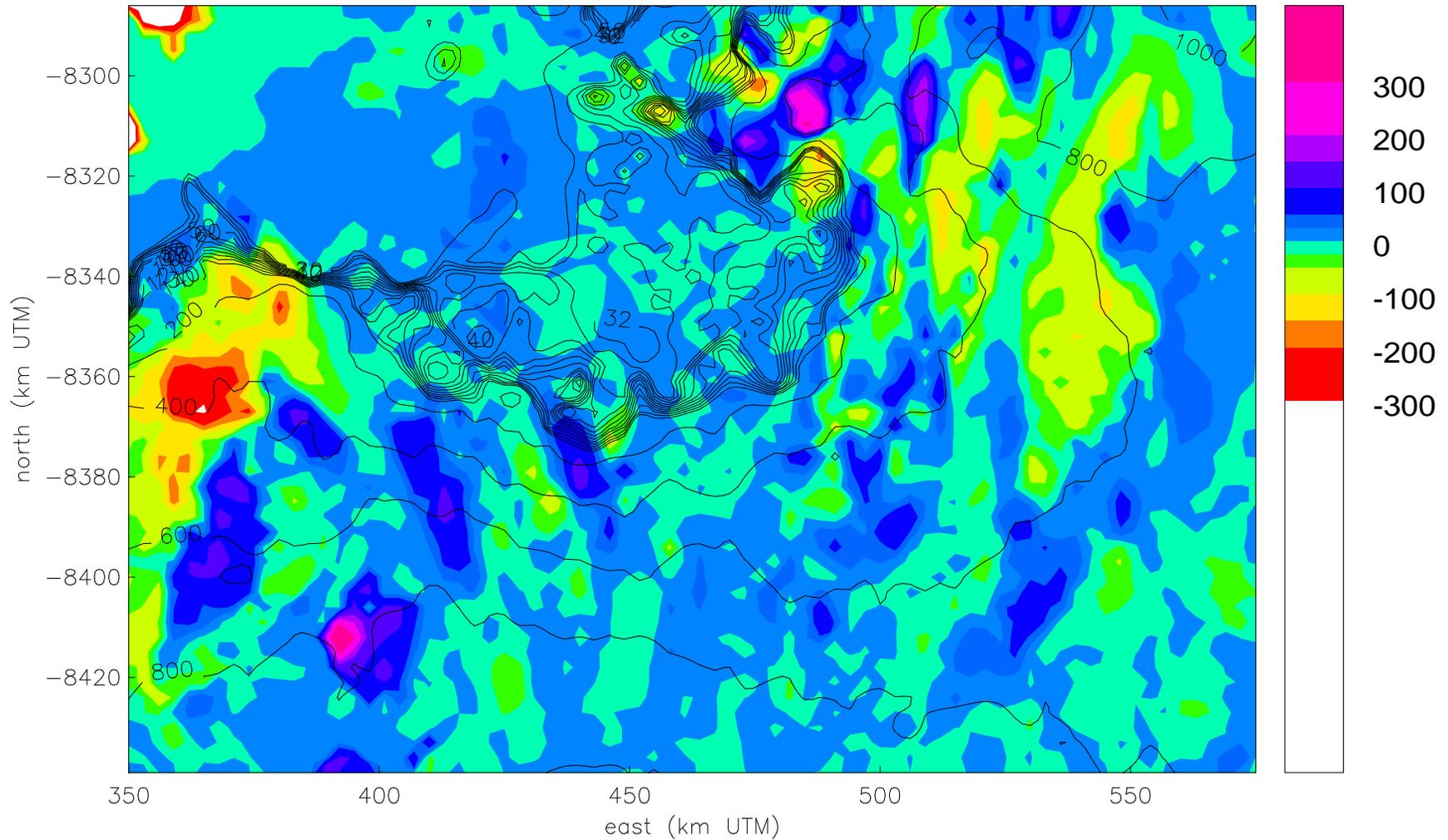


scale 1:2000000 diff.gla12 l3f-l2again.smallpine2.totps 20080927

diff.gla12 l3f-l2again.smallpine2.mx

# Change over 1 year 2006-05 (L3F) - 2005-05 (L3E)

Pine Island Glacier – GLAS (2006-05) minus GLAS (2005-05) [2003 cont]

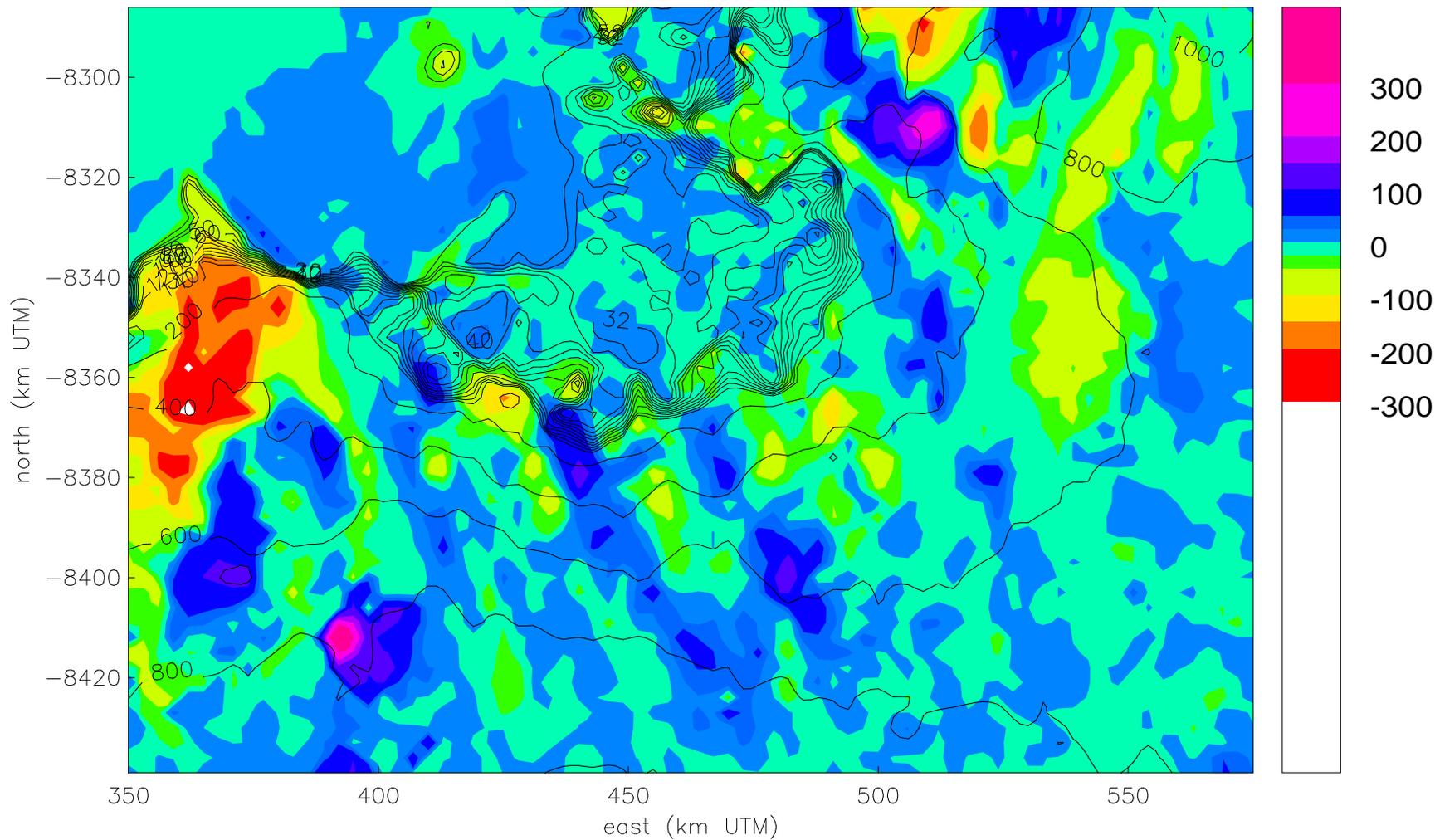


scale 1:2000000 diff.gla12 l3f-l3c.smallpine2.totps 20080927

diff.gla12 l3f-l3c.smallpine2.mx

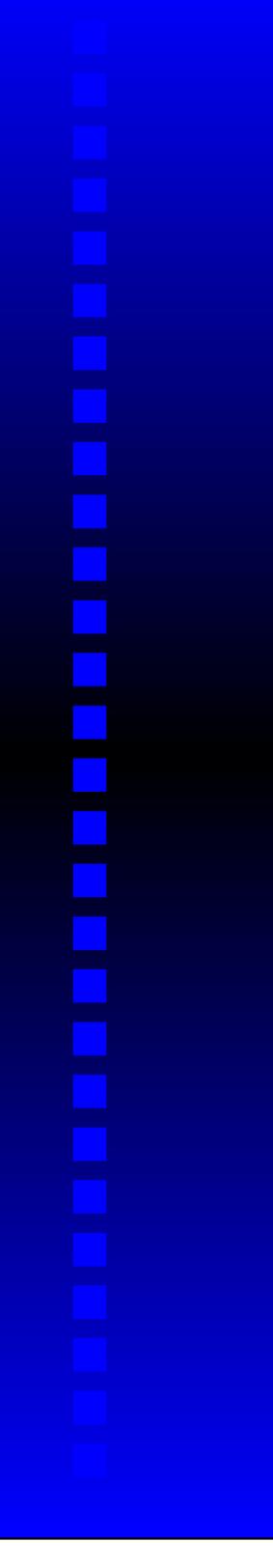
# Seasonal Signal 2006-05 (L3F) - 2006-02 (L3E)

Pine Island Glacier – GLAS (2006-05) minus GLAS (2003-10) [2003 cont]



scale 1:2000000 diff.gla12 l3f-l2again.smallpine2.totps 20080927

diff.gla12 l3f-l2again.smallpine2.mx



Conditional Simulation:

Scale-dependent fractal fields  
with natural roughness at every scale

# Role of Surface Roughness

To assess the potential of a multi-beam channel to measure high-resolution topography, we need information on **spatial subscale roughness** (ice surface roughness at a resolution higher than that of GLAS observations).

What is spatial surface roughness?

- a derivative of (micro)topography  
→ characterization of spatial behavior

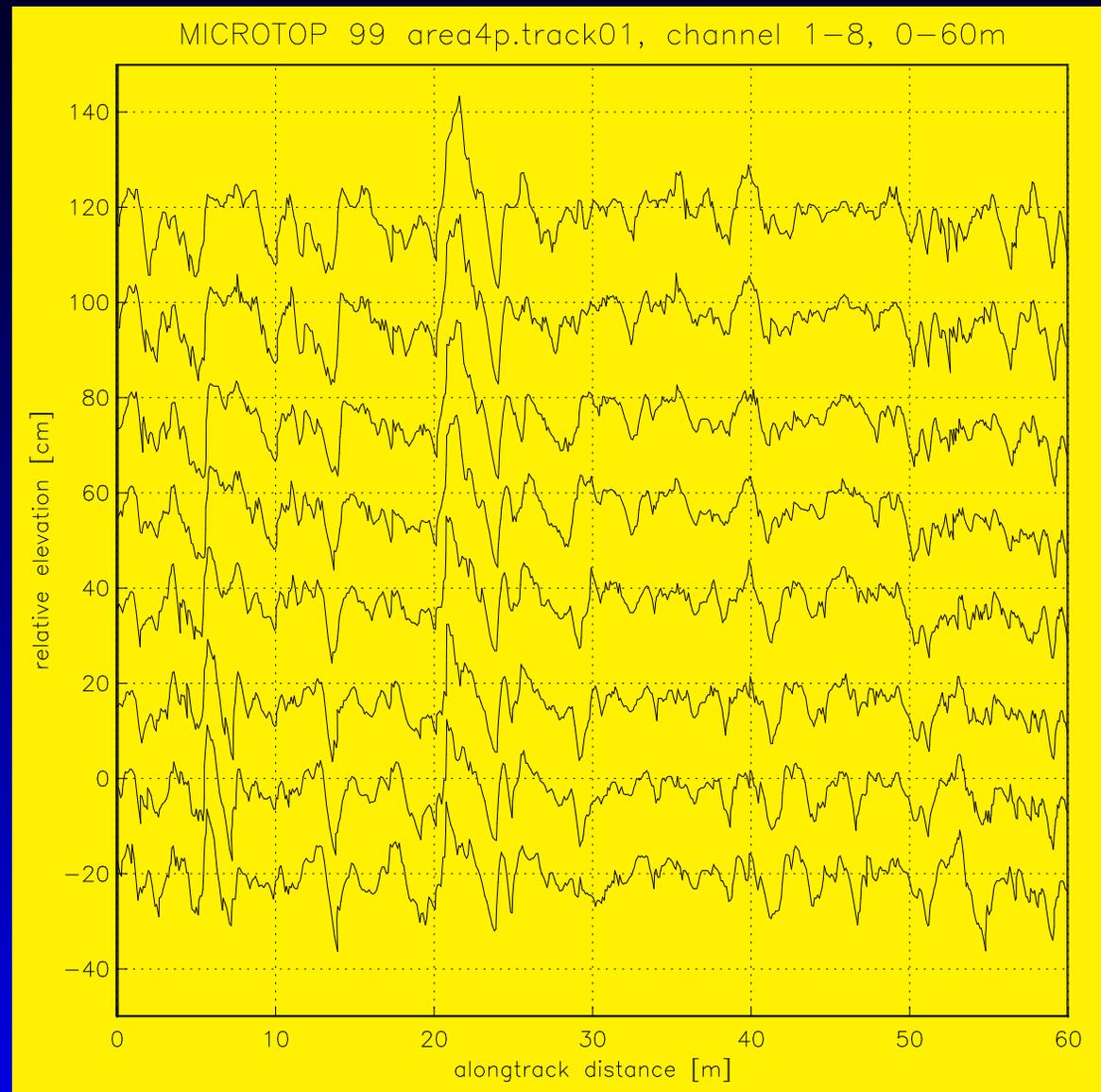
# (3.) How do we measure surface roughness? — The GRS !



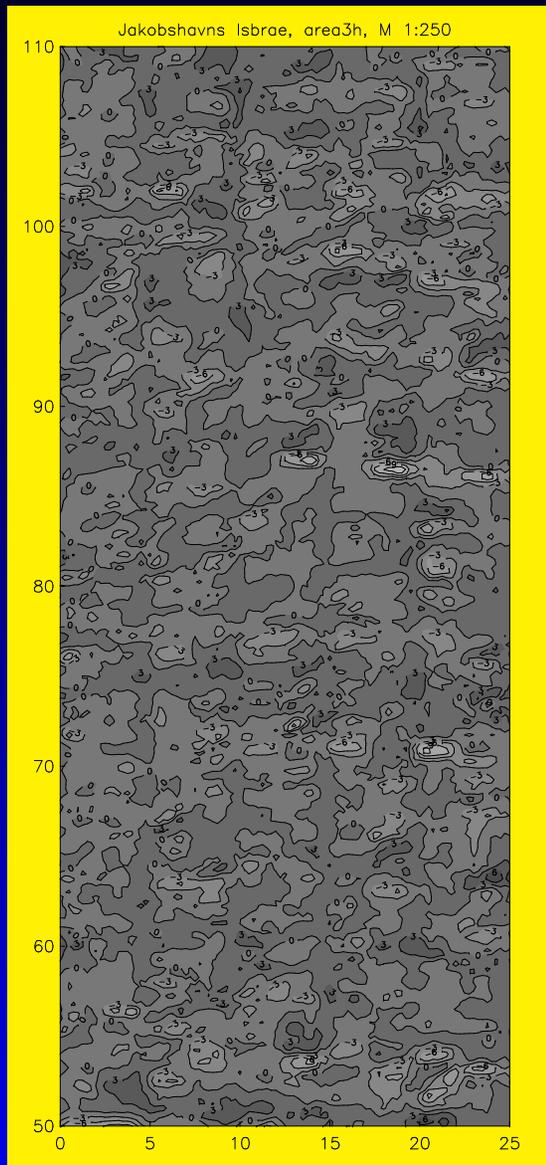
# Remote Sensing of Ice Surfaces

Data	Scales of Resolution
Radar Altimetry	3 km grids
MISR	275 m or 1,000 m pixels
SAR	12.5 m pixels
ATM	7 m resolution
Videography	Submeter resolution
The missing scale	
THE GRS	0.2 m resolution
Material properties	Microscopic scale

# GRS Data – Greenland Ice Sheet



# GRS Data – Roughness Model



## GRS Data

- data in 8 or 16 channels with across-track resolution 0.2 m
- along-track resolution  $\approx 0.1$  m
- subcentimeter vertical accuracy

## DEMs from GRS data

- 0.2m grids
- areas typically 25 m by 200 m to 200 m by 200 m

# Approach: Conditional Simulation of Ice Surfaces

- (1) Use GLAS DEMs as low-res boundary conditions
- (2) Use GRS data (from Greenland) to derive spatial surface roughness parameters using vario functions
- (3) Derive SIMSURF model parameters:
  - (a) scale breaks and their resolutions
  - (b) at every scale range:
    - (b.1) fractal dimension
    - (b.2) direction of anisotropy
    - (b.3) anisotropy factor
- (4) Use SIMSURF software (Herzfeld and Overbeck) to generate ice surface
- (5) Sample model data sets for SB and MB data
- (6) Analyze model data sets

# The SIMFRACT method for simulation of scale-dependent fractal surfaces with natural roughness at each scale

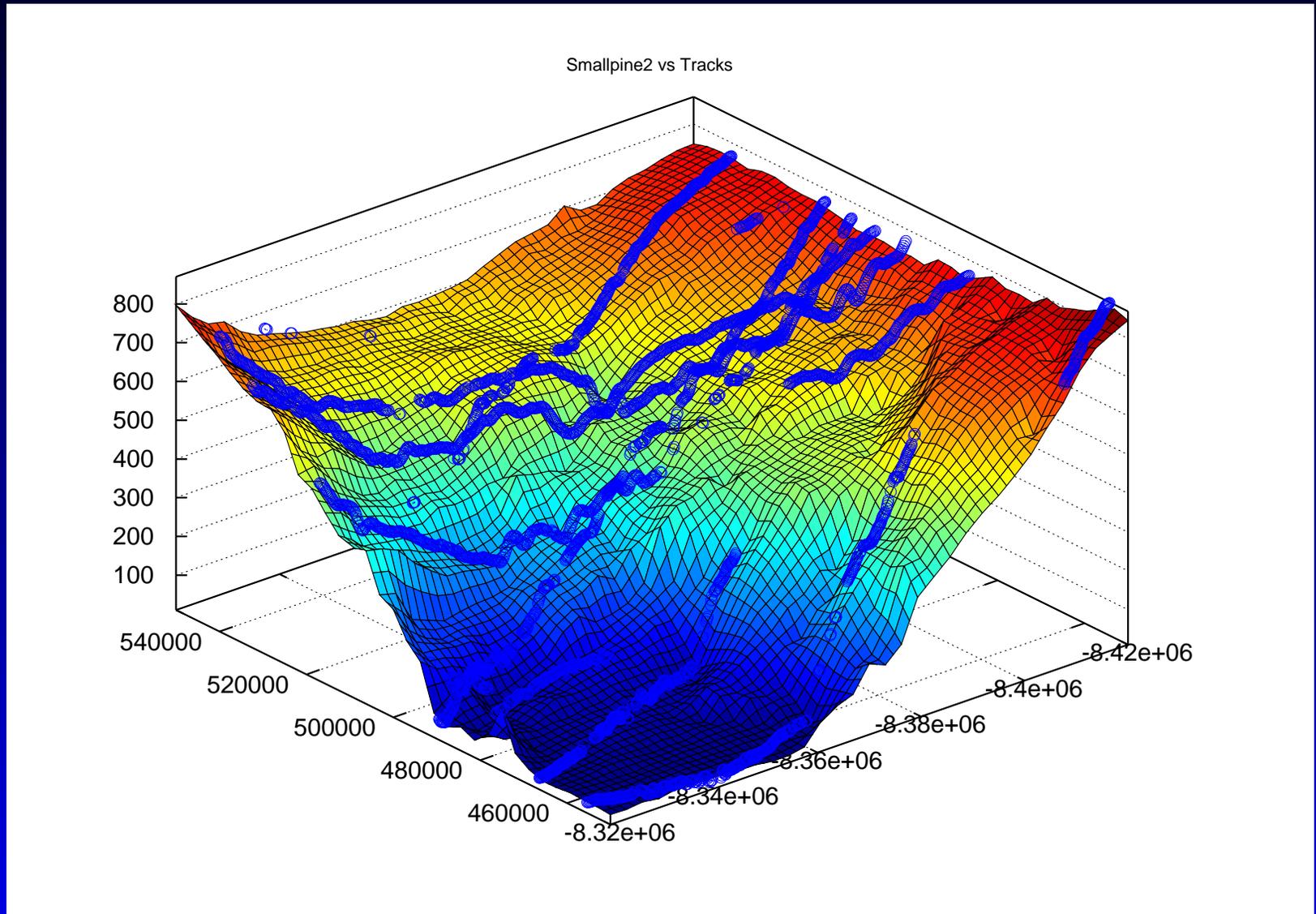
## (A) Data analysis part

- (1) Calculate scale-dependent dimensions (a - Variogram method, b - Fourier method, c - Isarithm method)
- (2) Determine homogeneity ranges of scale
- (3) Determine anisotropies at each scale range

## (B) Simulation part

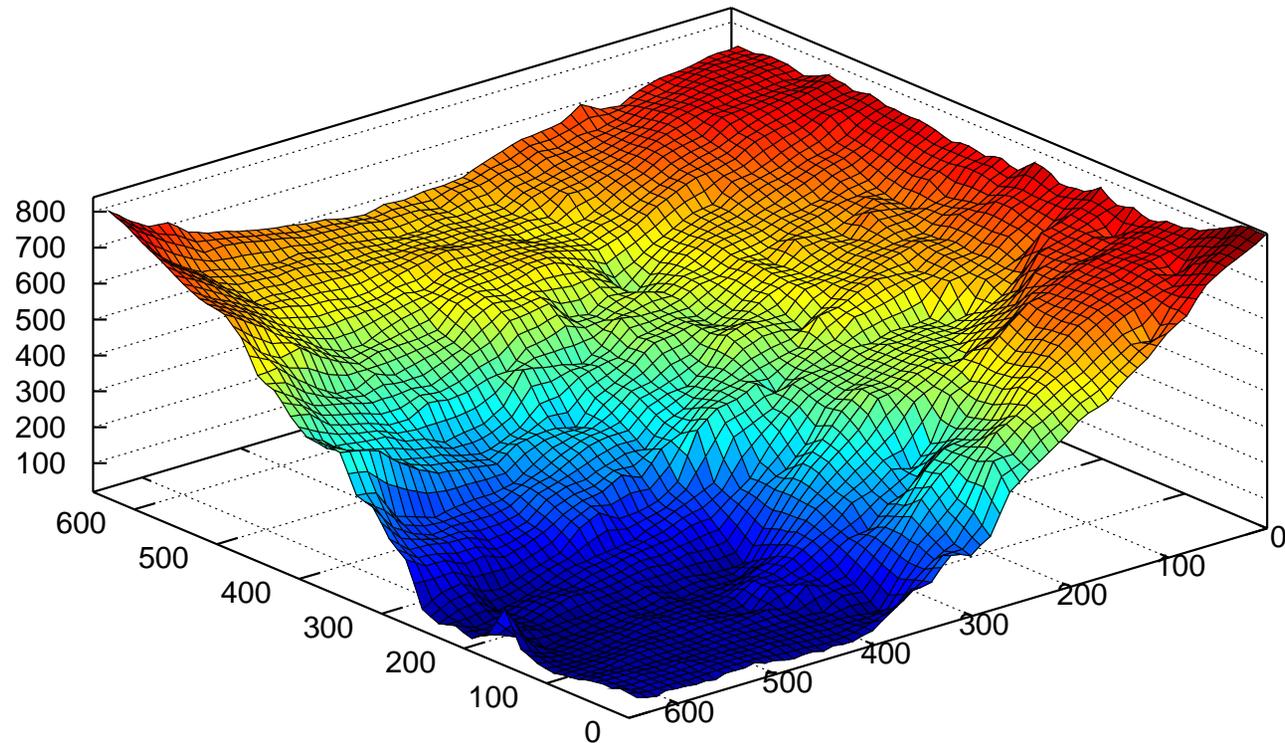
- (4) Set up a simulation network, matching scale breaks
- (5) Decide on scale ranges to interpolate versus ranges to simulate
- (6) Select interpolation method (Shephard, 4-pt)
- (7) Select simulation method (conditional, unconditional; using Fourier filter method for uncondl simulation of scale-dependent Fractional Brownian surfaces)
- (8) Select a method to merge scales

# Pine Island Glacier — L2A GLAS Data (2003)



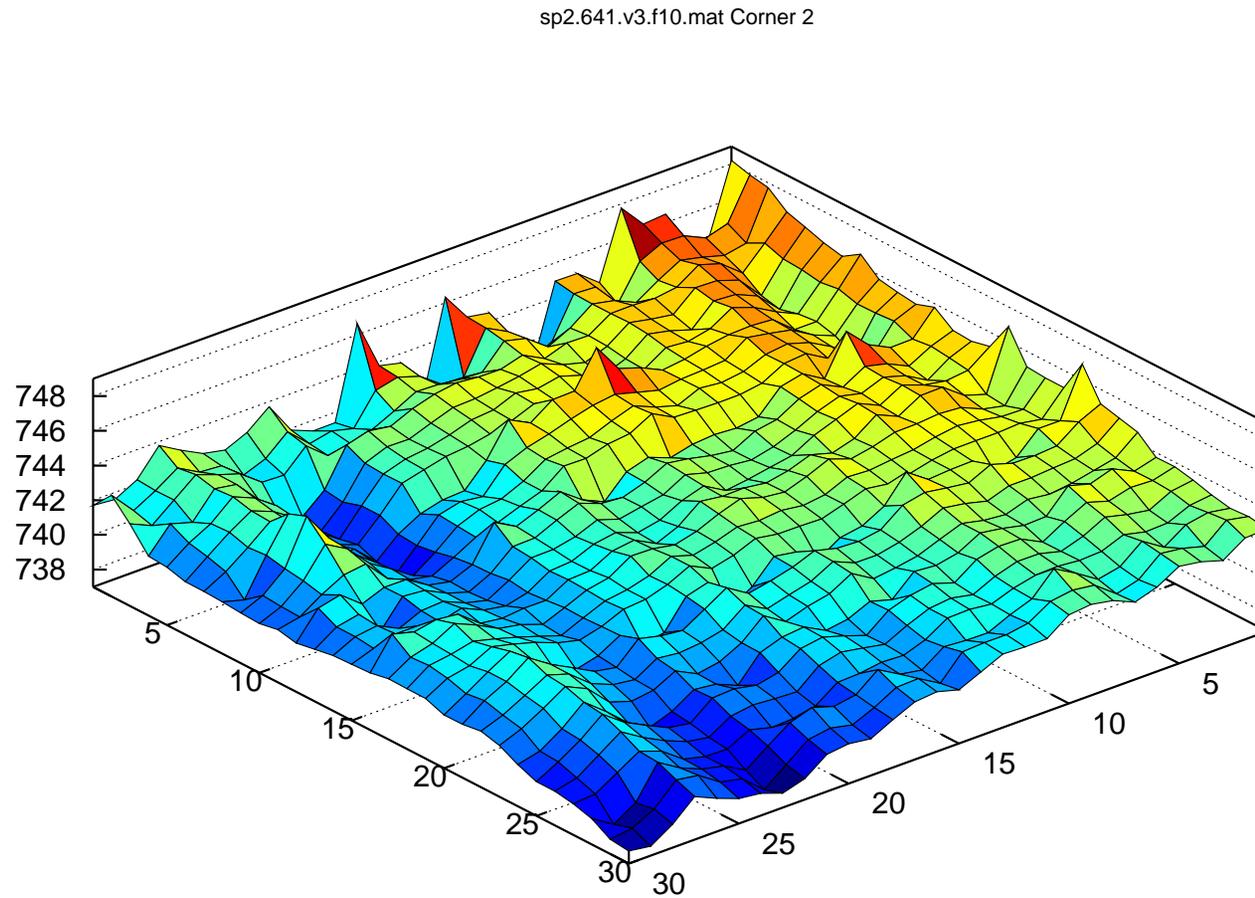
3D view upglacier, based on DEM from GLAS data, with GLAS data locations

# Conditional Simulation: Pine Island Glacier

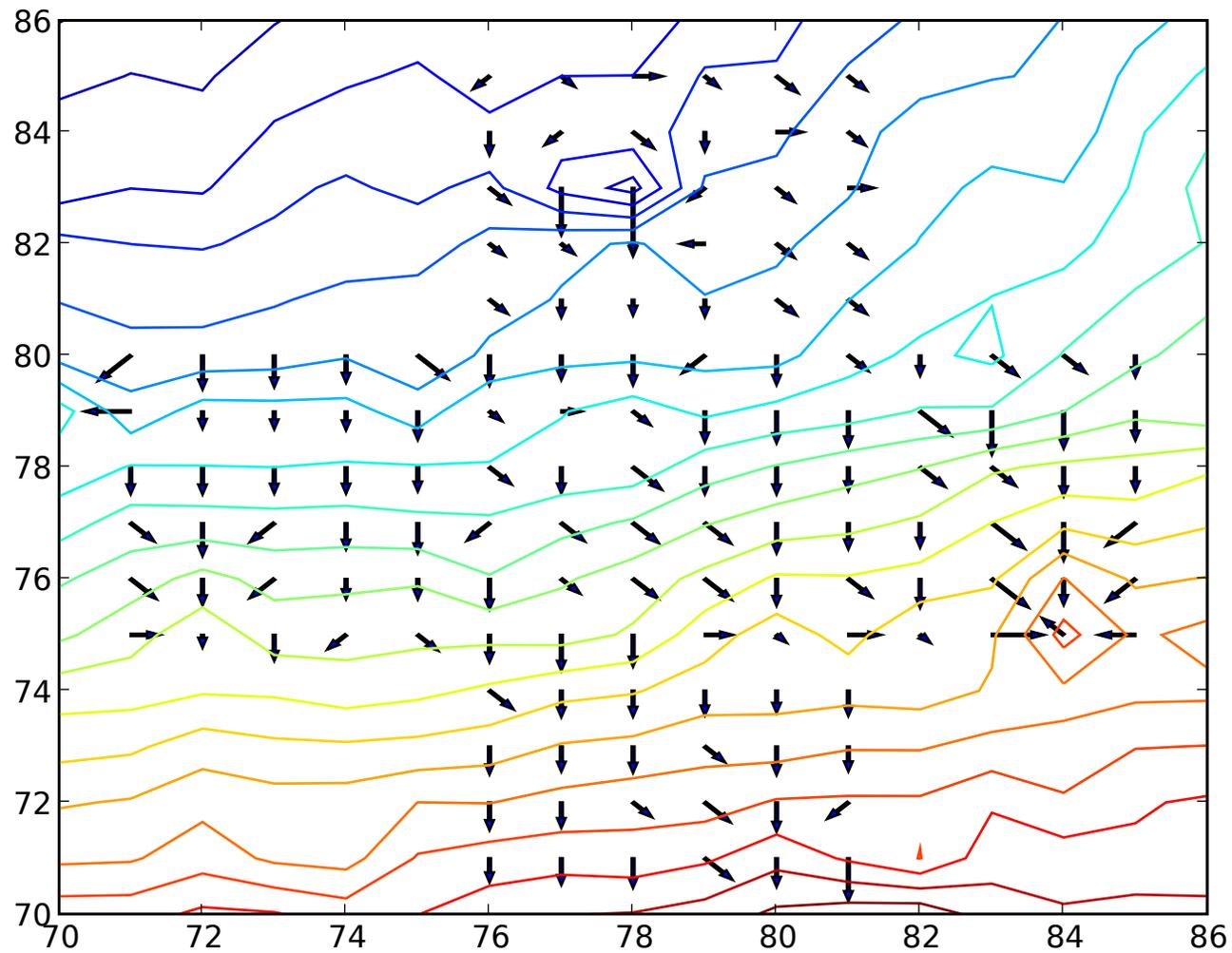


3D view upglacier, based on DEM from L2 (2003) GLAS data

# Conditional Simulation: Pine Island Glacier – Enlarged Subarea

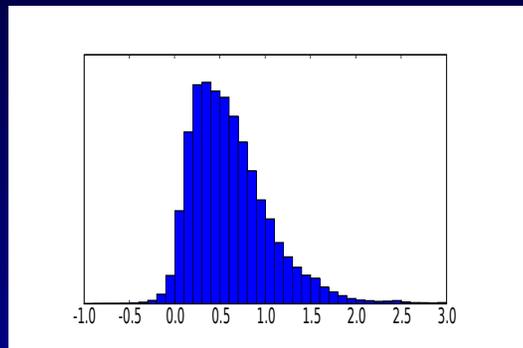


# Gradient Map from Multi-Beam Data



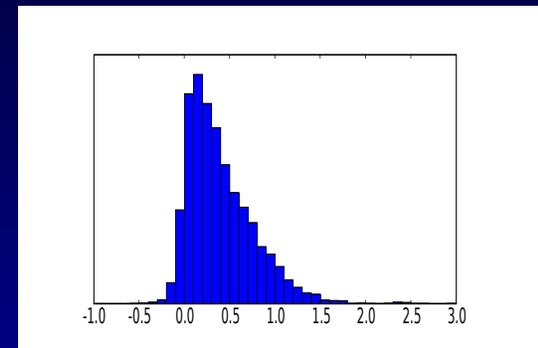
# Histograms of Gradients

Objective: Investigate how well variability of surface slope is captured in SB and MB (8beam) observations



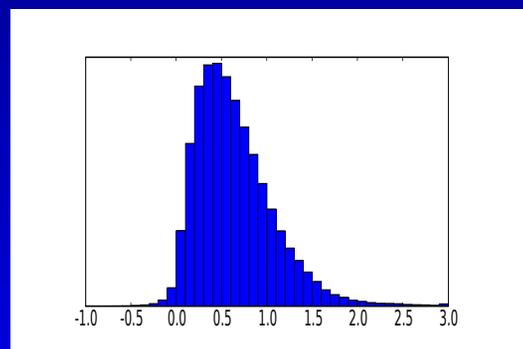
(A)

for MB data from Pinegl-Simul  
DEM (max. slope  $4.3^\circ$ )



(B)

for SB data from Pinegl-Simul  
DEM (max. slope  $2.9^\circ$ )



(C)

for entire Pinegl-Simul DEM.  
(max. slope  $4.9^\circ$ )

# Questions?



# Conclusions Multi-Beam -2

## (A) Multi-Beam or only Single-Beam Lidar for ICESat-2?

- (1) Multi-beam lidar observations will yield 3-dimensional information on land and sea ice elevation
- (2) Locally-known hi-res elevation captures gradient and directional derivative distribution of the entire surface to 99.9 percentile
- (3) Spatial statistical properties from swath data can be used to extrapolate between ground tracks

→ With a MB system, ICESat-2 can meet and advance the “Decadal Survey” objectives for cryospheric observation, change detection, modeling and prediction.

## (B) Swath Mapper (16 Beams) — Split Beam (4 or 2 Beams)

### (1) Swath Mapper

- (a) Achieves superior spatial resolution and hence better accuracy and more spatial information (as in (A)) (140m gradient fields, 0.85m along-track sampling)
- (b) More susceptible to cloud/ aerosol caused data loss, but studies so far indicate good spatial data collection
- (c) Instrument to date only tested on aircraft

### (2) Split Beam

- (a) Twice the track density as SB, with 140m offset data in 2° rotated mode
- (b) Cannot derive gradient fields with 140m grids, but across-track slope locally, otherwise 4km gradient fields
- (c) Split-beam technology with pulse-repetition lidar with specs similar to GLAS